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DESIGN OF A DATA ACQUISITION AND REDUCTION SYSTEM FOR FATIGUE T--ETC(U)
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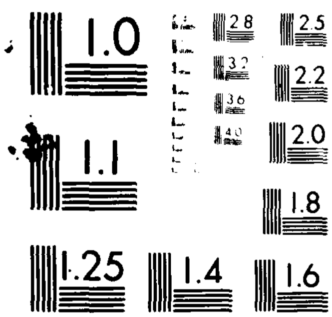

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

DESIGN OF A DATA ACQUISITION
AND REDUCTION SYSTEM FOR FATIGUE TESTING

by

Jerry Wayne Dalton

September 1981

Thesis Advisor: Gerald H. Lindsey

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A data acquisition and reduction system has been created for aircraft materials fatigue testing. The system uses an HP-9835 Desktop Calculator, an HP-2240A Measurement and Control Processor and a Materials Testing System loading machine. Three different computer programs on the HP-9835 are used to analyze material properties, simulate inflight fatigue loading and compute fatigue damage at a stress concentration. The flight loads are selected from Mil Spec 8866 and applied in a random order. The fatigue

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damage at a stress concentration is calculated from the applied local stresses using Miner's Law.

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Design of a Data Acquisition and Reduction System for Fatigue Testing

by

Jerry Wayne Dalton
Lieutenant, United States Navy
B.S., University of Texas at Austin, 1975

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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Author: ______________________

Approved by: ______________________ Thesis Advisor

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Dean of Science and Engineering

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A data acquisition and reduction system has been created for aircraft materials fatigue testing. The system uses an HP-9835 Desktop Calculator, an HP-2240A Measurement and Control Processor and a Materials Testing System loading machine. Three different computer programs on the HP-9835 are used to analyze material properties, simulate inflight fatigue loading and compute fatigue damage at a stress concentration. The flight loads are selected from Mil Spec 8866 and applied in a random order. The fatigue damage at a stress concentration is calculated from the applied local stresses using Miner's Law.

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I. INTRODUCTION

Today's high cost of aircraft dictates that the lifetimes of existing and new aircraft be extended as long as possible. The data acquisition system and computer programs described in this thesis will permit more realistic fatigue testing of aircraft materials; thereby enabling the engineer to predict and design more accurately for fatigue life.

The programs are set up to start with a standard tension test to determine the modulus of elasticity and the Ramberg-Osgood coefficients to model the plastic region. The second program is for flight load simulation of a specific number of flight hours to be applied to a specimen with a given stress concentration. This program was designed to apply loads that would be experienced by fighter aircraft, the loads being randomly ordered after being selected from the Military Specification 8866 1000 flight hour spectrum. The load data from this test is stored in sequence on magnetic tape, and local strain information is gathered at the point of stress concentration via pictures of photo-elastic patterns taken during the test. The last program assesses the damage incurred by the specimen during the flight simulation. This program is specialized to predict damage for specimens fabricated from 7075-T6 Aluminum.

II. CONCEPTS

A. STRESS AND STRAIN CALCULATIONS

Lindsey has developed [Ref. 1] a series of equations for calculating local stresses at stress concentration sites, which use a nonlinear stress-strain law and account for residual stresses and strains. The analysis assumes that the notch tip behaves in many respects like a uniaxial tension specimen with a Ramberg-Osgood description.

$$\varepsilon = \frac{\sigma}{E} + \beta\left(\frac{\sigma}{E}\right)^n \tag{1}$$

Loading the specimen of Figure 1 to a nominal stress of S psi, the local stress can be found by solving

$$K_t S = \sigma\left[1 + \beta\left(\frac{\sigma}{E}\right)^{n-1}\right] \tag{2}$$

where

K_t = Elastic Stress Concentration Factor

During the unloading portion of the cycle, Lindsey showed, via energy considerations, that the residual stress was given by

$$\sigma_R = \sigma - \left[\sigma^2 + \frac{2n\beta E^2}{n+1}\left(\frac{\sigma}{E}\right)^{n+1}\right]^{1/2} \tag{3}$$

where σ is the local stress at the notch at the peak of the loading cycle as found from Equation (2) above. This stress will be compressive and will be non-zero only if σ exceeds

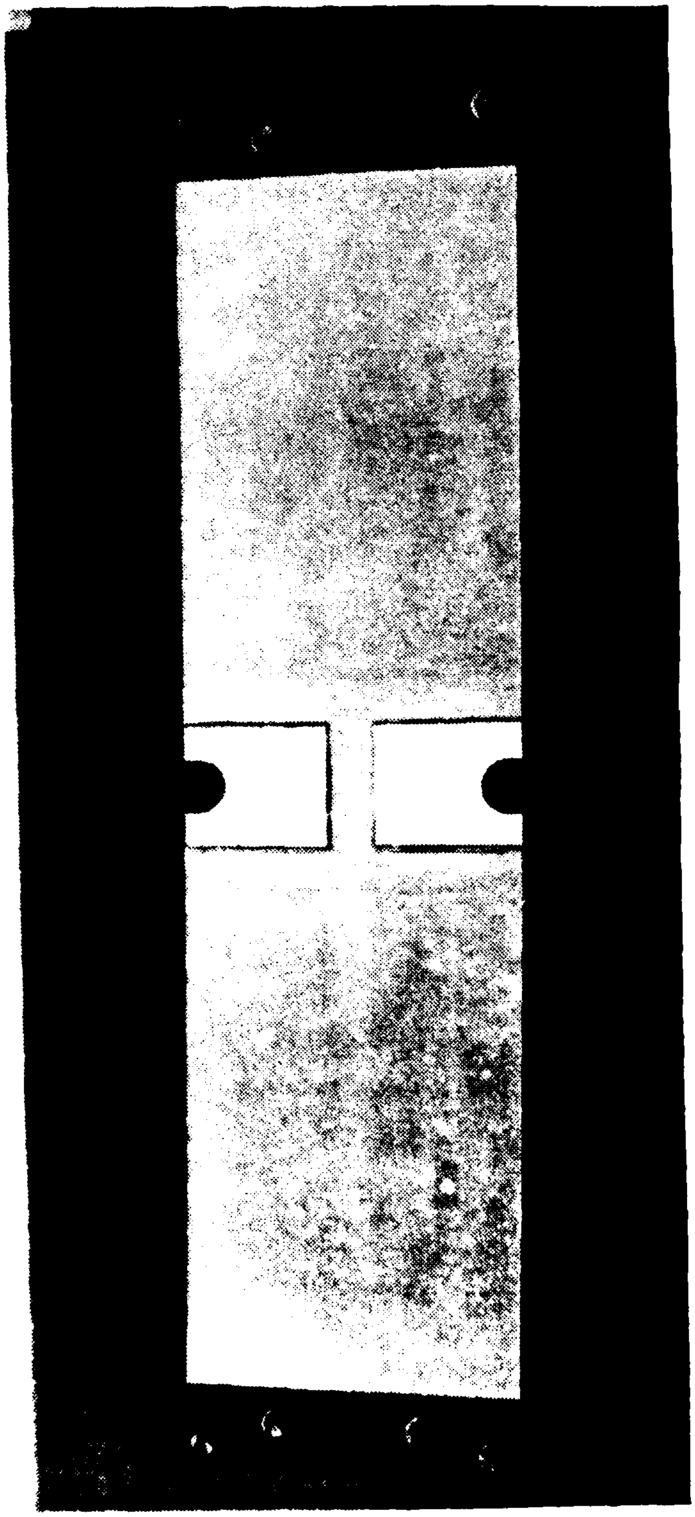


Figure 1. Sample Test Specimen

the proportional limit by a significant amount. The residual strain is positive and given by

$$\varepsilon_R = \frac{\sigma_R}{E} + \beta\left(\frac{\sigma}{E}\right)^n \qquad (4)$$

These values of stress and strain become the starting points for the next cycle, and the R fatigue parameter is calculated taking the residual stress into account. (The R value is the ratio of the minimum stress to the maximum stress.) The elastic stress in subsequent cycles is given by

$$\sigma = \sigma_R + K_r S - E\varepsilon_R \left[1 + \frac{S}{S_{\substack{\text{Last}\\\text{Yield}}}}\right] \qquad (5)$$

At the next yield, a new residual stress and strain must be calculated from Equations (3) and (4).

B. MILITARY SPECIFICATIONS FOR FATIGUE

In order to analyze materials and structures for fatigue, it is necessary to have some knowledge of the types of loads and the number of loading cycles that the structure will be subjected to. For this purpose Military Specification 8866 Flight Loading Spectrum A has been chosen (Table I). This spectrum was chosen by the military for loadings that were expected on fighter-type aircraft for each 1000 hours of flight time. The military expects these aircraft to have a lifetime of 4000-6000 hours under this type of loading.

TABLE I

FLIGHT LOAD SPECTRUM A

% Limit Load	Number of Cycles
35	17,000
45	9,500
55	6,500
65	4,500
75	2,500
85	1,360
95	440
105	150
115	40
125	16

C. STANDARD USED FOR MATERIAL PROPERTIES

The reference material specifications for fatigue life were taken from NACA TN 2324 [Ref. 2]. Testing was done on sheet 75S-T6 Aluminum (Al 7075-T6) for various R values. The results of these tests were plotted in Figure 2. Regression equations were formulated using the BMDP Biomedical Computer Programs [Ref. 3] by inputing the data points in Table II that were selected off Figure 2.

The best regression formula (Table III) was found by using the actual R value and the stress divided by 10,000. The output value was the logarithm of the number of cycles

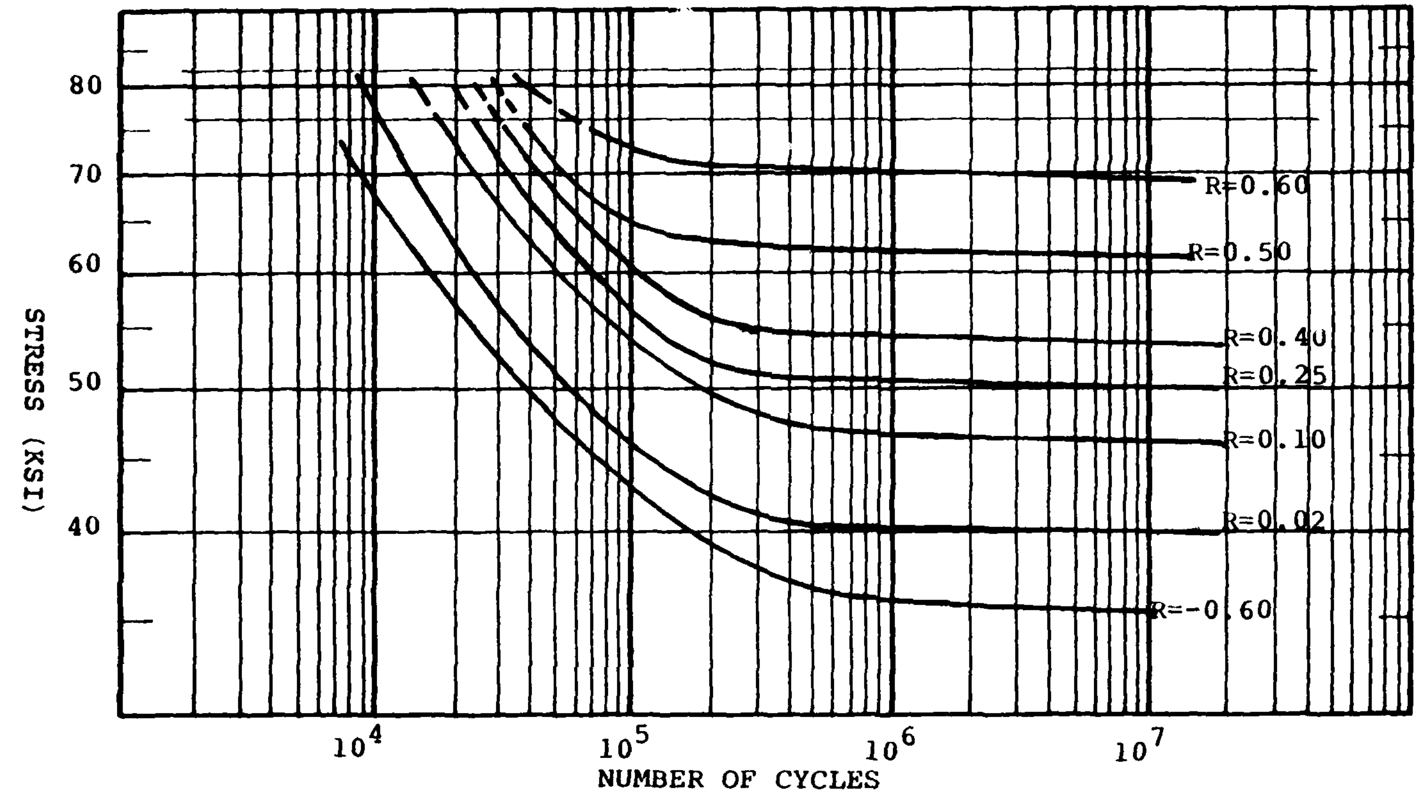


Figure 2. S-N Diagram for 7075-T6 Aluminum

TABLE II

DATA POINTS USED FOR REGRESSION EQUATIONS

N	LOG N	R=-0.60	R=0.02	R=0.10	R=0.25	R=0.40	R=0.50	R=0.60
1E4	4.0000	67500	77000	-	-	-	-	-
2E4	4.3010	57000	62000	73500	80000	-	-	-
3E4	4.4771	52800	57000	67000	72000	76100	81000	-
4E4	4.6021	49900	53500	63000	67200	71400	75000	79200
6E4	4.7782	46500	49500	58000	61500	65500	69000	75000
1E5	5.0000	43200	45500	54000	56500	60500	64800	72500
2E5	5.3010	39100	42200	49400	52000	55700	62500	70500
3E5	5.4771	37500	41000	48300	51000	54800	62300	70200
6E5	5.7782	35200	40500	47000	50500	54000	62000	70000
1E6	6.0000	34500	40100	46500	50300	53900	61900	69800

TABLE III

REGRESSION COEFFICIENTS

Term	Coefficient
INTERCEPT	12.6452
S	-1.92662
S^4	2.81098E-3
S^8	-3.10691E-7
R^2	-12.8099
R^6	212.476
R^8	-86.7650
SR	3.68800
S^3R	-0.112720
S^5R	1.04762E-3
S^7R^3	3.39637E-6
S^3R^4	-3.50885E-2
S^4R^6	-1.61827E-2
SR^9	-34.4642

S = Stress/10000

R = Minimum Stress/Maximum Stress

to failure (N). Thus, the logarithm of N is the sum of the terms shown in Table III. This gave a multiple correlation coefficient of 0.96167. Table IV shows the correlation of the regression output to the input values of Table II.

TABLE IV

REGRESSION EQUATION CORRELATION

OBSERVED	PREDICTED						
	R=-0.60	R=0.02	R=0.10	R=0.25	R=0.40	R=0.50	R=0.60
4.0000	3.9473	3.9532	-	-	-	-	-
4.3010	4.4561	4.2822	4.3987	4.3372	-	-	-
4.4771	4.5001	4.4084	4.5079	4.5122	4.3652	4.5818	-
4.6021	4.5594	4.5682	4.5818	4.6042	4.3989	4.5777	4.4482
4.7782	4.6915	4.8329	4.7535	4.8307	4.6342	4.8648	4.8706
5.0000	4.9057	5.1857	4.9766	5.1665	5.0204	5.2530	5.2119
5.3010	5.3123	5.5398	5.3346	5.5763	5.5343	5.5250	5.5317
5.4771	5.5166	5.6817	5.4359	5.6798	5.6437	5.5505	5.5831
5.7782	5.8565	5.7428	5.5630	5.7331	5.7438	5.5892	5.6179
6.0000	5.9709	5.7925	5.6140	5.7547	5.7565	5.6022	5.6530

Although the regression predicted output does not look like a close correlation to the observed data, the error of the regression equation falls within the scatter band for the original data [Ref. 2].

III. DESCRIPTION OF ACQUISITION SYSTEM

The data acquisition system consists of an HP-9835 Desktop Computer (Controller), an HP-2240A Measurement and Control Processor (Processor), and a Materials Testing Machine (MTS). The Controller (Fig. 3) is used to generate the random loads, send the loads to the MTS through the Processor and manipulate the strain data that it receives back through the Processor. The Processor (Fig. 4) receives digital commands from the Controller to output specified analog values or to read analog values and send them in digital form to the Controller. The MTS (Fig. 5) is a hydraulic testing machine that applies loads specified by voltage signals to a test specimen.

The resident language in the Controller is BASIC in which all of the programs are written. Programs and data are stored on a built-in magnetic tape mass storage device. The Controller is linked to the Processor (or any other peripherals) through the HP-IB Interface Bus. This Bus has its own Read Only Memory (ROM) and address associated with the ROM. Each peripheral on the Bus also has its own HP-IB address. The Processor is addressed by the Controller through the HP-IB by use of the ENTER and OUTPUT commands, which include the device address and the data to be sent or requested.

Figure 3. HP-9835 Desktop Computer

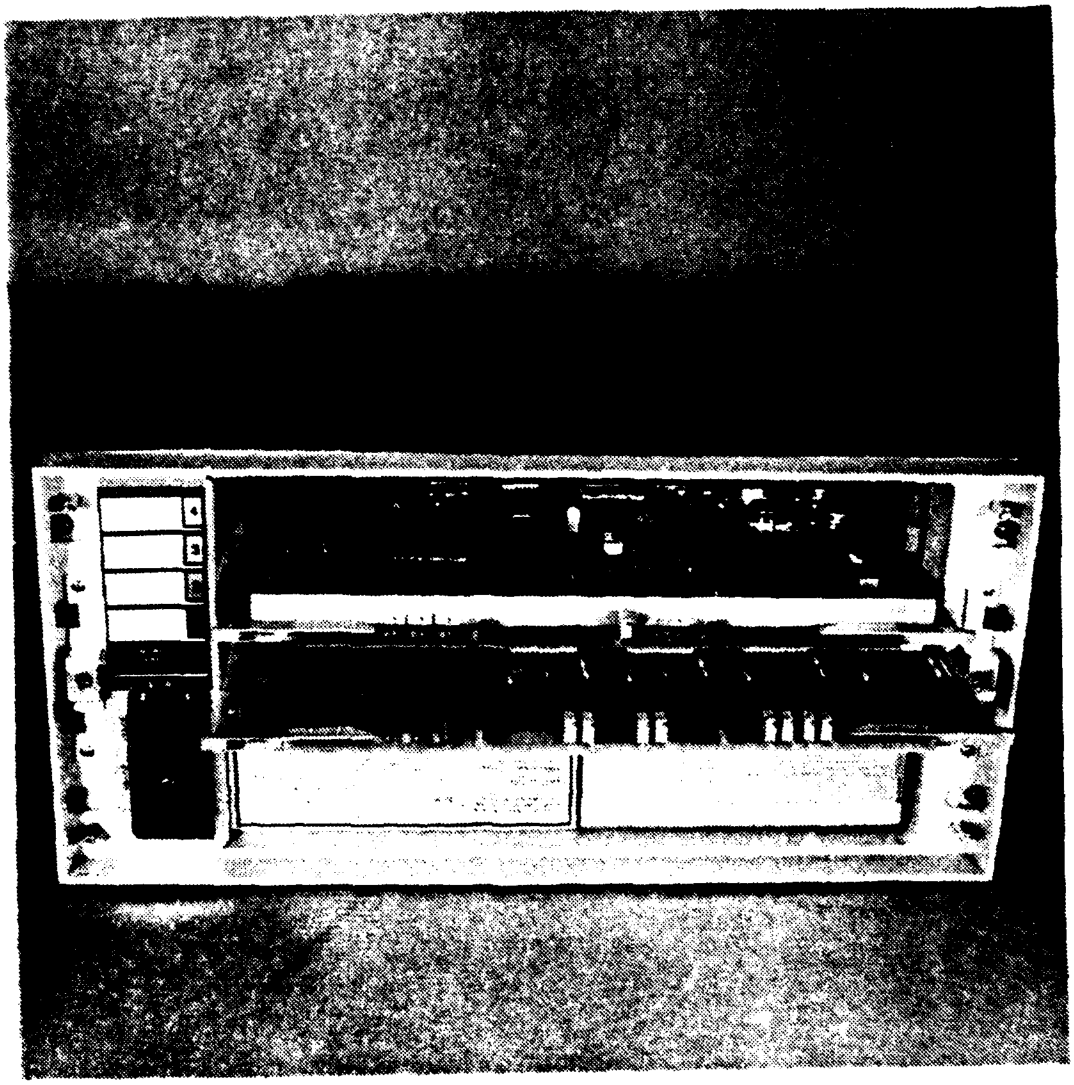


Figure 4. HP-2240A Measurement and Control Processor

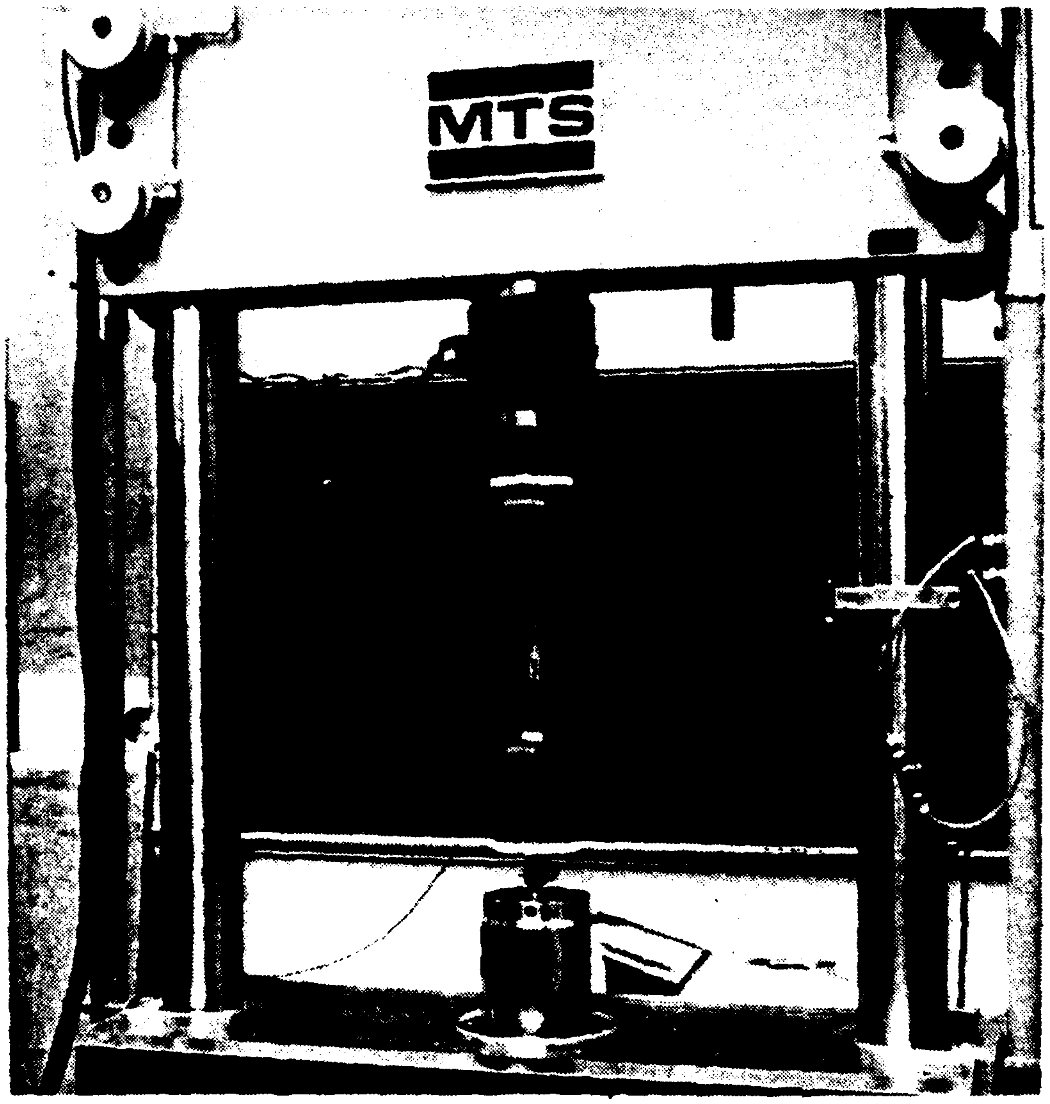


Figure 5. Materials Testing System (MTS)

The Processor has four function card slots. For this data acquisition system one D/A card and one A/D card were all that were necessary. The D/A card can handle up to four output channels, one is used to drive the MTS and another is used to drive a relay, which operates an automatic camera shutter. The A/D card can handle up to sixteen bi-polar channels. In this instance eight were used by the acquisition program for reading strain gages, and/or load cells. Commands are sent to the Processor in standard ASCII format, and an error code is sent back to the Controller.

The MTS is a 100,000 lb., closed loop, feedback controlled Materials Test System with a hydraulic actuator. The MTS can be used in either load, strain or displacement control modes. It can be used by itself with its own controller or its own function generator. In this case the output from the D/A card was input to the MTS in a load control mode. The signal from the Processor was output to the hydraulic system and the MTS checks itself with a load cell signal until the load is matched.

IV. DESCRIPTION OF PROGRAMS

There are three major programs written for the controller (in BASIC) for material properties and fatigue testing. The first is entitled AXIAL and is used to record data from a strain gaged specimen in an axial tension test to determine the Modulus of Elasticity, Poisson's Ratio and the Ramberg-Osgood coefficients for the plastic region. FLTTST, the second program, generates random ordered loads and outputs these loads through the PROCESSOR to the MTS System, which applies the loads to the specimen. The loads and the strains generated by this program are stored on tape for use later in data reduction. The last program, DAMAGE, takes the data generated by FLTTST and calculates the fatigue damage of the specimen.

A. PROGRAM AXIAL

AXIAL does not control the MTS System and so can be used with any system possessing voltage outputs for load and strain to record data. AXIAL records data while the testing machine performs an axial tension pull on a test specimen. The program is set up to read the load and both the longitudinal and transverse strains at equal intervals of time while the testing machine is used in a constant strain rate mode. The program can also be run using only the longitudinal strain gage in which case Poisson's ratio is not computed.

The loads are converted to stresses so that the program can work directly with the stress-strain relationships. After all the data has been taken, the program asks the user to specify the load at which the proportional limit seems to have been reached. This cutoff is entered so that a good linear fit can be made to find the Modulus of Elasticity (E). After the linear fit to obtain E, the value is output along with the slope intercept B and the correlation factor. The program then asks the user if a different fit is to be tried using a new proportional limit. If not, the program continues by computing Poisson's ratio and finds the Ramberg-Osgood coefficients using the Modulus of Elasticity previously found.

The Modulus of Elasticity is the most critical property found in AXIAL not only for its own value in calculating stresses and strains but also because the Ramberg-Osgood coefficients are based on E. For this reason a good linear fit is obtained by a routine that evaluates the perpendicular distances of the data points from the estimated fit. The E that has been calculated is output to the user along with the correlation factor so that a judgment can be made as to whether the estimated proportional limit should be changed in order to try for a better fit.

The equations governing the linear elastic portion of the stress-strain curve are:

$$\sigma_1 = A\varepsilon_1 + B \qquad (6)$$

$$\sigma_1 = C\varepsilon_2 + D \qquad (7)$$

where A is the modulus of elasticity (E). B and D are normally neglectibly small. Poisson's ratio is given by

$$\nu = -\frac{A}{C} \tag{8}$$

The plastic portion of the stress-strain curve can be approximated by the following equation:

$$\varepsilon = \frac{\sigma}{E} + \beta\left(\frac{\sigma}{E}\right)^n \tag{1}$$

Beta and n can be found by performing a logarithmic curve fit of the data above the proportional limit, but the Ramberg-Osgood method gives as good a fit with fewer calculations. The Ramberg-Osgood relations are:

$$n = 1 + \frac{\log (17/7)}{\log (\sigma_{.7}/\sigma_{.85})} \tag{9}$$

$$\beta = \frac{3}{7}\left(\frac{E}{\sigma_{.7}}\right)^{n-1} \tag{10}$$

where,

$\sigma_{.7}$ = stress at the intersection of a line of slope .7E and the stress-strain curve

$\sigma_{.85}$ = similarly computed with a slope of .85E.

Inputs for AXIAL are:

Maximum Strain for the test

Strain Rate to be used

Number of Data Points desired (1000 max)

Number of Strains to be recorded (1/2)

Cross Sectional Area of specimen

Load Scale Factor (pounds/millivolt)

Strain Scale Factor (microstrain/millivolt)

After the data run:

Maximum Load of Elastic Range (Proportional Limit)

B. PROGRAM FLTTST

The most critical program is FLTTST since it both controls the MTS and takes data. The key to FLTTST is the random selection of the load to be applied to the specimen. Using the Mil Spec 8866 Flight Loading Spectrum A for fatigue, percentages were calculated for the number of times each load is to be applied (Table V). These percentages were then totaled and left in decimal form as numbers between 0 and 1. Then, using the Controller's random number generator, the load to be applied is selected through a series of IF statements. For example, to select a load of 95% of limit load, a random number above 0.98462125 and below 0.99509594 has to be selected. If after going down through all of the IF statements a load is not selected, it would mean that the random number must be above 0.99961910, then 125 limit load has been selected, the MTS load is incremented in finite load steps that are user selected. When the desired load is reached, the Controller than requests that the Processor read the data channels. FLTTST then stores these data points on tape for future reduction. As each load to be output is selected, a count is kept of

that load so that the user can have an immediate output of the load distribution at the end of the run.

TABLE V

RANDOM NUMBER FOR SELECTING MANEUVER LOAD

% Limit Load	# Cycles	Random Number
35	17,000	0.40470409
45	9,500	0.63086226
55	6,500	0.78560206
65	4,500	0.89272961
75	2,500	0.95224492
85	1,360	0.98462125
95	440	0.99509594
105	150	0.99866686
115	40	0.99961910

Inputs for FLTTST are:

Number of Hours to be simulated

Number of Data Readings (maximum of 8)

Load at One G (lbs)

Limit Load (lbs)

Load Scale of MTS (10,000;20,000;50,000;100,000)

Load Rate (lbs/sec), and

Data Reading Scale Factor (microstrain or pounds/millivolt)

There is another program named RDDATA that may sometimes be needed after running FLTTST. If data from more than one strain gage or load cell were recorded on the data file from FLTTST, it is necessary to first run RDDATA to separate each data file under its own heading before proceeding with program DAMAGE. This was done to conserve time between data points taken and to extend the life of data tapes. It also conforms with program DAMAGE since it can only compute damage on one set of data at a time.

C. PROGRAM DAMAGE

The purpose of this program is to take the loading that was saved on tape with the FLTTST program and calculate the fatigue damage accumulated at the stress concentration site during the flight hours simulated. The program reads the recorded far-field loads in the order that they were applied to the specimen, calculates local stresses at the stress riser and then uses Miner's Law for calculating the cumulative damage. Once the load creates a stress in the critical area greater than the proportional limit, local stresses are calculated using a nonlinear stress-strain law and calculations for residual stresses and strains are made.

The maneuver load and the one G load stored immediately after it are read in together. The maneuver load is then converted to nominal or far-field stresses and local stresses using the following relations:

$$S = \frac{L}{A} \qquad (11)$$

$$\sigma = K_t S \tag{12}$$

where,

S = nominal stress

L = applied load

A = minimum cross sectional area of specimen

σ = local stress

K_t = stress concentration factor

The local maneuver stress is checked against the proportional limit or the last largest plastic stress to see if it would cause plastic deformation. If plastic deformation is produced, then an iteration process must be performed to find the local stress, using the relation

$$K_t S = \sigma[1 + \beta(\frac{\sigma}{E})^{n-1}] \tag{2}$$

The routine to do this uses a modified false position method [Ref. 4]. With the local stress determined, residual stresses and strains are then calculated, using

$$\sigma_R = \sigma - [\sigma^2 + \frac{2n\beta E^2}{n+1} (\frac{\sigma}{E})^{n+1}]^{\frac{1}{2}} \tag{3}$$

$$\varepsilon_R = \frac{\sigma_R}{E} + \beta(\frac{\sigma}{E})^n \tag{4}$$

If no new plastic deformations are caused but the plastic region has been entered before, then local stresses are calculated using

$$\sigma = \sigma_R + K_t S - E\varepsilon_R[1 + \frac{S}{S_{\substack{\text{Last}\\\text{Yield}}}}] \tag{5}$$

where $S_{\substack{Last\\Yield}}$ is the largest nominal stress that has occurred which produced local stresses into the plastic region.

Damage is then calculated using the current local stress and the ratio of the current stress to the stress at one G loading (R value).

Using Miner's Law:

$$D = \frac{1}{N} \tag{13}$$

where, N = number of cycles to failure and can be found using regression formulas that fit stress-fatigue data for 7075-T6 aluminum. The damage caused by this cycle is then added to the damage caused by the other cycles computed one load at a time until all the data has been read.

Inputs to DAMAGE are:

Minimum Cross Sectional Area (sq. in.)

Modulus of Elasticity (psi)

Ramberg-Osgood Coefficients, and

Proportional Limit (psi)

V. SAMPLE TEST

Several tests have been developed to evaluate both the programs and the program-acquisition system combined. AXIAL was checked by inputting stress and strain pairs taken from an existing Ramberg-Osgood representation of 7075-T6, and the results of the two were compared. FLTTST was checked by taking the output from the Processor (normally used to drive the MTS), routing the output from the output port to the input port and reading the output value on the data input port. Thus, the input port was getting input just as it normally would from a load cell. By doing this the actual voltages could be read directly from the output port with a voltage meter, and the input results could be treated as actual loads to check Program DAMAGE. This was checked by hand for both load spectrum and load accuracy. DAMAGE was checked by hand with sample runs through FLTTST as described above. Two full system tests were then run with the MTS, including photo-elastic pictures of the stress concentration area and strip chart recordings of the input and output loads.

A. PROGRAM AXIAL

The first test of AXIAL was performed by using the Ramberg-Osgood coefficients calculated by Kaiser [Ref. 5] to generate stress-strain pairs for manual input into the

program. The result should have been the same value for the modulus of elasticity and the Ramberg-Osgood coefficients as previously computed. Since a relatively small number of points were entered by hand (53) as compared to the number of points that will be taken by the program (1000), larger errors were expected on this test than will be expected on an actual data run. The results of the test are shown below.

Kaiser	AXIAL
E = 10.117E6	E = 10.113E6
n = 21.58	n = 23.475
β = 1.479343	β = 1.5177E47

This large difference (especially in β) was due to the stress-strain pairs being calculated in stress steps of 500 psi. The program, using 1000 points, will have a difference of approximately 16 psi between points. This will make the accuracy of the program better than the capability of the system to read loads and strains accurately.

The second test of AXIAL was an actual specimen tension test. A specimen of 7075-T6 Aluminum was fabricated from the same sheet stock as the notched panel specimens. This was inserted into the MTS machine which was operated in a constant strain rate mode. The specimen was loaded to produce a strain of 14,000 microinches/inch, at a strain rate of 1000 microinches/inch/minute. One thousand data points were taken at constant intervals of strain during the test. The program then computed the modulus of elasticity

and the Ramberg-Osgood coefficients. These were compared to hand calculations made from the Load vs. Strain plot made by the MTS. The results of both are listed below.

AXIAL	Hand Calculation
E = 9.5042E6	E = 9.5000E6
n = 31.2154	n = 33.0383
β = 3.1168E63	β = 9.7360E66

A plot of the actual data and the points computed using the calculated material properties are shown in Figure 6.

B. PROGRAM FLTTST

The first test performed with FLTTST was one to see if the random load spectrum followed and Mil Spec load spectrum. This was done by making several runs of 100 hour simulations and comparing the spectra (Table VI). As would be expected, the spectra did not match exactly due to the random way in which loads were chosen. The largest differences were in the area of the fewest loads, as also would be expected. A sample from a strip chart of the Processor output and the output from a load cell while the MTS is being driven by FLTTST is shown in Figure 7.

Several sample tests were run to check the accuracy of FLTTST and DAMAGE. Knowing that a full system test was going to be run, the sample tests were run using the material properties of the specimen (Fig. 1) to be used in the full scale tests. These material parameters and properties are:

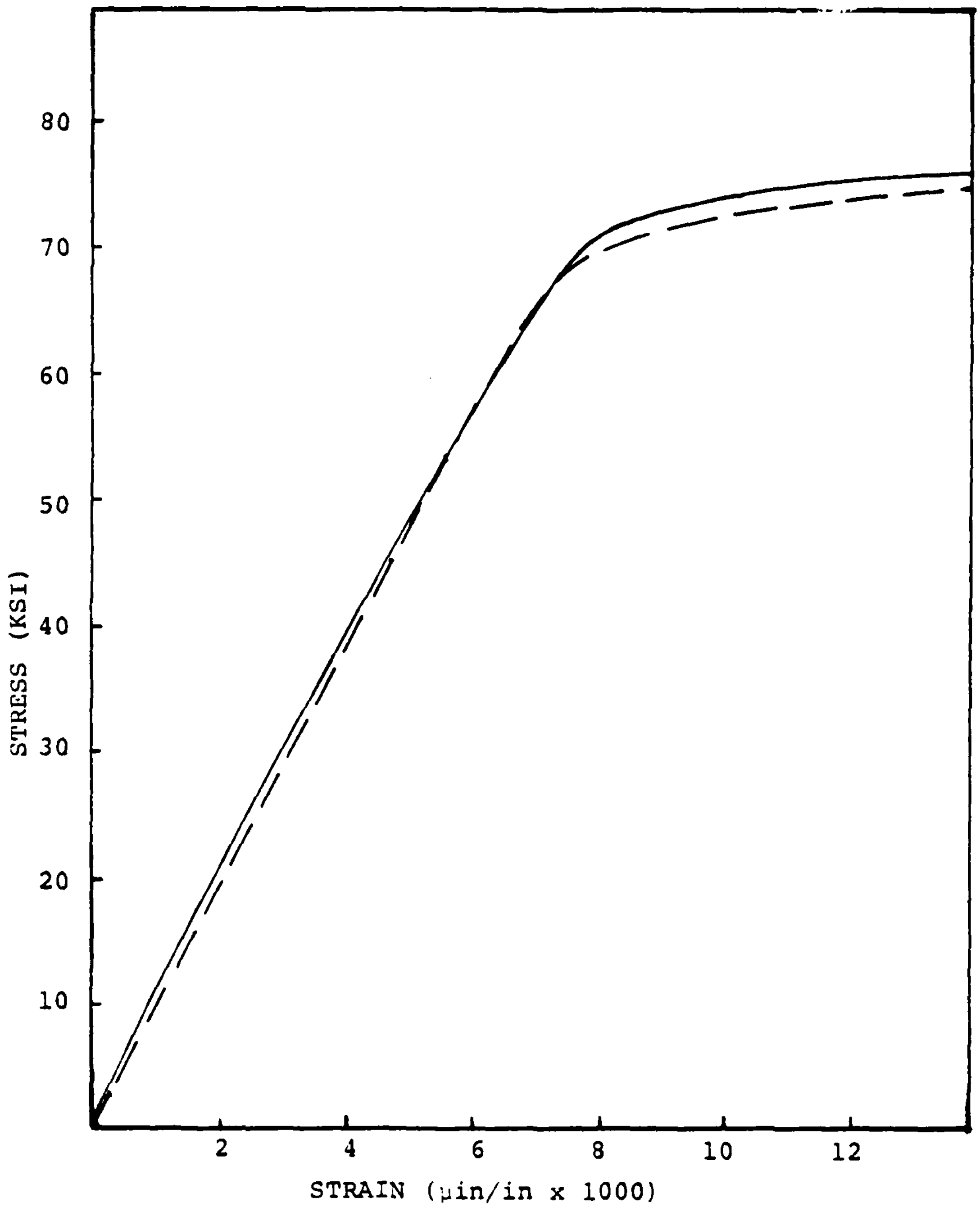


Figure 6. Axial Tension Test

$A = .7136$ sq. in.

$E = 10.12$ E 6 psi

$K = 2.73$

$\beta = 1.479$ E 43

$n = 21.58$

$\sigma_Y = 72{,}000$ psi

$\sigma_{ULT} = 82{,}000$ psi

$\sigma_{PL} = 60{,}000$ psi

TABLE VI

SAMPLE LOAD SPECTRA

% Load	MIL SPEC	100HR	100HR	100HR	100HR
35	17000	1698	1726	1662	1721
45	9500	977	998	948	937
55	6500	658	637	690	646
65	4500	451	434	442	450
75	2500	228	234	246	250
85	1360	133	139	146	131
95	440	49	21	43	53
105	150	13	8	15	8
115	40	5	1	6	3
125	16	0	2	2	1
	42006	4200	4200	4200	4200

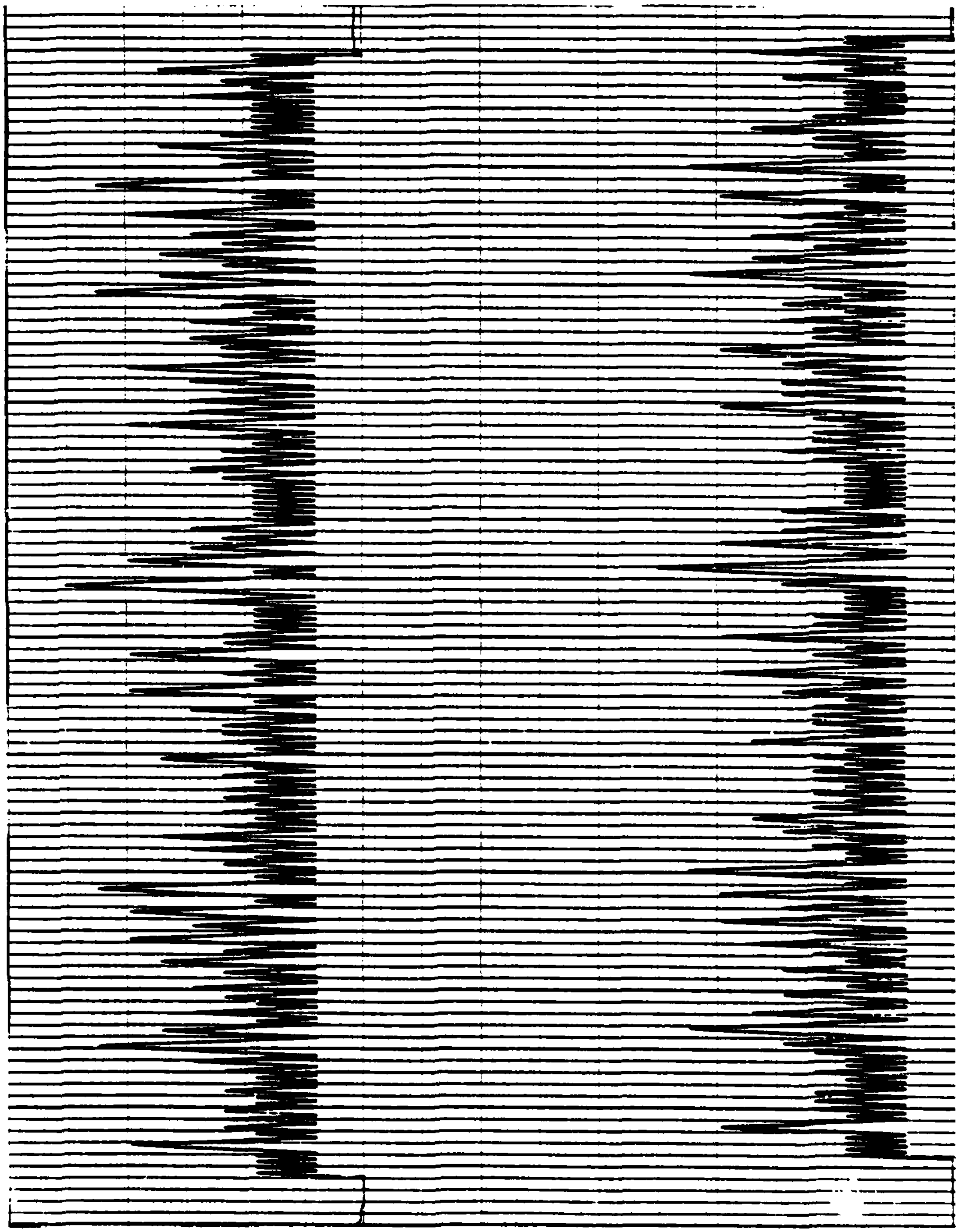


Figure 7. Sample Random Loading

For these uses the limit load was set at the load that would cause local yield stress or at two-thirds of the ultimate stress, whichever was the lower. In this case two-thirds the ultimate stress was the limiting factor which gave a limit stress of 54,667 psi, produced by a load of 14,289 lbs. Assuming a 6.5-g aircraft limit load, this gave a 1-g stress of 8409 psi, produced by a load of 2198 lbs. These are the limits asked for by the program FLTTST and all other loads are fractions of the limit load. The 1-g load is used as the minimum load in the fatigue cycle.

To check the accuracy and speed of different loading step sizes, sample calculations were performed and compared with the computed actual load that should be applied (Table VII). For this check the material properties of the sample specimen were used. The conclusions were that a step size of 25 should be used since this gives good accuracy and takes approximately four minutes per hour of flight time simulated.

C. PROGRAM DAMAGE

Further tests were performed primarily to check the DAMAGE program, but the FLTTST program was used to generate some of the loads to run through DAMAGE. The first was a handmade test of ten cycles that had one load that would send the specimen into the plastic region locally and other loads that would produce recordable damage. The purpose of this check was to check the program's calculation of the

TABLE VII

STEP SIZE COMPARISONS

	CALCULATED			STEP = 25			STEP = 100		
%LOAD	LOAD	S	Kt*S	LOAD	S	Kt*S	LOAD	S	Kt*S
100	14289	20024	54665	14289	Not Computed		14289	Not Computed	
1-y	2198	3080	8409	2150	3013	8225	2000	2803	7651
35	5001	7008	19132	5050	7077	19320	5200	7287	19893
45	6430	9011	24599	6450	9039	24676	6600	9249	25249
55	7859	11013	30066	7900	11071	30223	8000	11211	30605
65	9288	13016	35533	9300	13033	35579	9400	13173	35691
75	10717	15018	41000	10750	15064	41126	10800	15135	41317
85	12146	17021	46467	12150	17026	46482	12200	17096	46673
95	13575	19023	51934	31600	19058	52029	13600	19058	52029
105	15003	21024	57397	15050	21090	57576	15200	21300	58150
115	16432	23027	62863	16450	23052	62932	16600	23262	63506
125	17861	25029	68330	17900	25084	68480	18000	25224	68862

PLASTIC STRESS COMPUTATIONS

%LOAD	LOAD	S	STRESS	LOAD	S	STRESS	LOAD	S	STRESS
115	16432	23027	62544	16544	23052	62605	16600	23262	63116
125	17861	25029	66942	17900	25084	67046	18000	25224	67306

residual stresses and strains and the difference in damage due to those residual stresses and strains. There were three loads that caused damage (85%, 95% and 125% limit load) and one load that caused local stresses above the proportional limit (125% limit load). Residual stresses and strains were calculated along with the total damage and compared with the program's results (Table VIII). Differences in calculations were within roundoff error.

TABLE VIII

TEN CYCLE LOAD SPECTRUM

% LIMIT LOAD	LOAD (lbs)	STRESS	R	D
35	5001.15	19133	0.4395	0
65	9387.85	35532	0.2367	0
45	6430.05	24599	0.3418	0
85	12145.70	46465	0.1810	1.0324E-6
125	17861.30	66944	0.1048	3.0193E-5
35	5001.15	17725	0.3957	0
95	13574.60	50488	0.1389	3.8419E-6
45	6430.05	23185	0.3025	0
75	10716.80	39567	0.1772	0
55	7858.95	28646	0.2448	0

HAND CALCULATION

σ_R = 1313 psi $\qquad$ ε_R = 7.3442E-6 in/in

D = 3.5067E-5

PROGRAM CALCULATION

σ_R = -1313 psi $\qquad$ ε_R = 7.3443E-6 in/in

D = 3.5077E-5 $\qquad$ σ = 66,944 psi

The last set of tests ran the entire system. Program FLTTST was used to drive the MTS, and output from the MTS load cell was read by the program and stored on tape. Photoelastic pictures were taken of the specimen before the test and during the test at every load above 75% of the limit load. A strip chart reading of the program output and the load cell output (Fig. 7) were read out simultaneously to enable immediate analysis of the program load and MTS load correlation.

TABLE IX

THREE HOUR FLIGHT SIMULATION TEST

#LOADS	%LOADS	STRESS	R	D
2	85	46482	0.1770	1.0726E-6
3	95	52029	0.1581	4.4607E-6
2	105	57576	0.1429	1.2222E-5

HAND CALCULATION RESULTS

D = 3.9972E-5

PROGRAM RESULTS

D = 3.9902E-5

The first test was a three flight hour simulation and the second was a two-hour simulation. During both tests the highest load applied to the specimen was 105% of the limit load. By reference to Table VII, 105% of the limit

load does not cause local stresses above the proportional limit; therefore, no residual stresses need to be calculated and all the 1-g stresses will be the same. The results of the tests (Tables IX and X) show that the program and hand calculations agree within round-off error.

TABLE X

TWO HOUR FLIGHT SIMULATION TEST

#LOAD	%LOAD	STRESS	R	D D
3	85	46482	0.1770	1.0726E-6
1	105	57576	0.1429	1.2222E-5

HAND CALCULATION RESULTS

D = 1.5440E-5

PROGRAM RESULTS

D = 1.5534E-5

VI. CONCLUSIONS

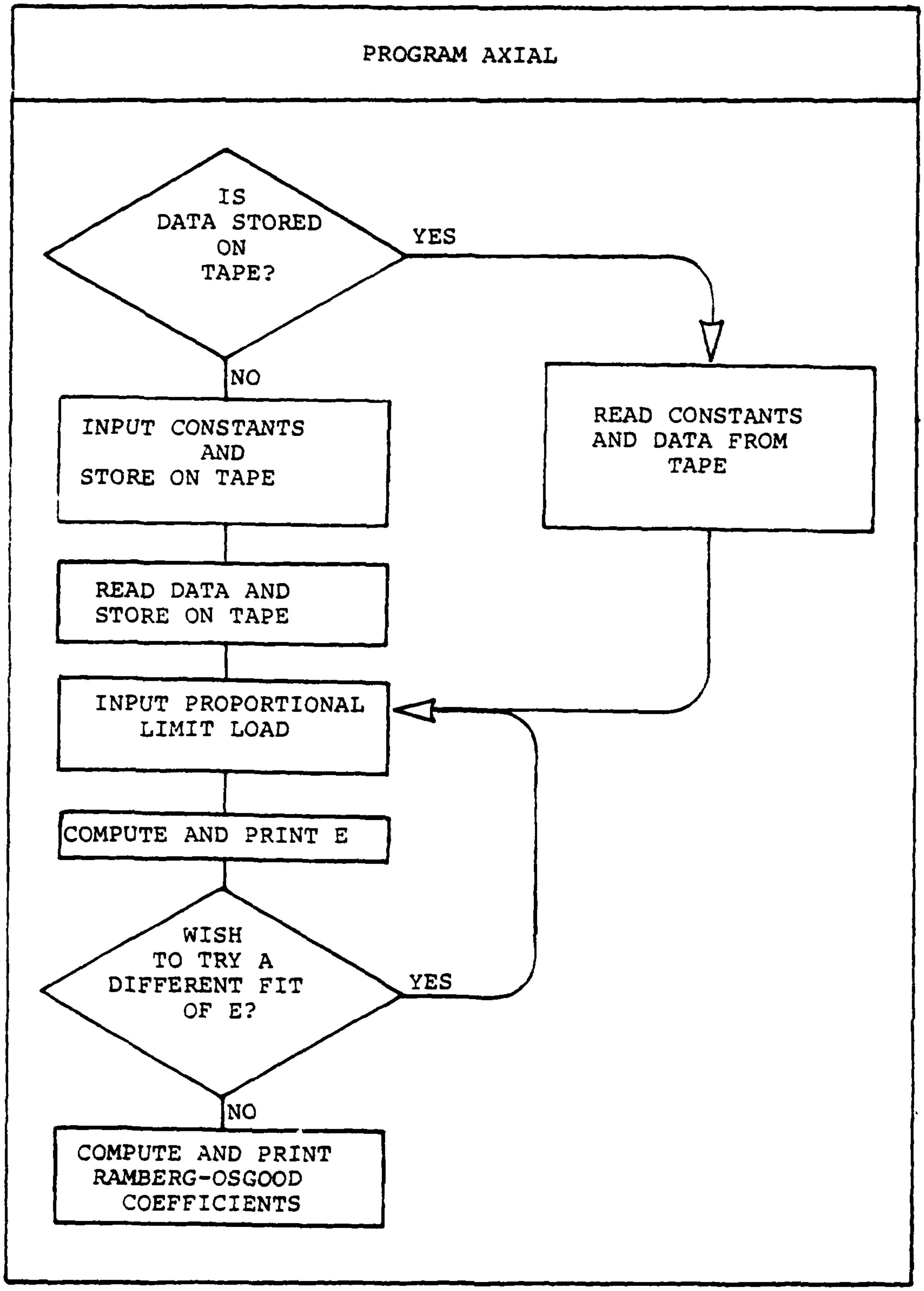
It is believed that this system will greatly simplify and increase the accuracy of predicting fatigue damage. Almost all of the calculations that would normally have to be done by hand, one step at a time, are now performed by the programs. A few of the input values were left as hand calculations as a safety feature, so that the user would be aware of the magnitude of the loads at which the MTS would be operating.

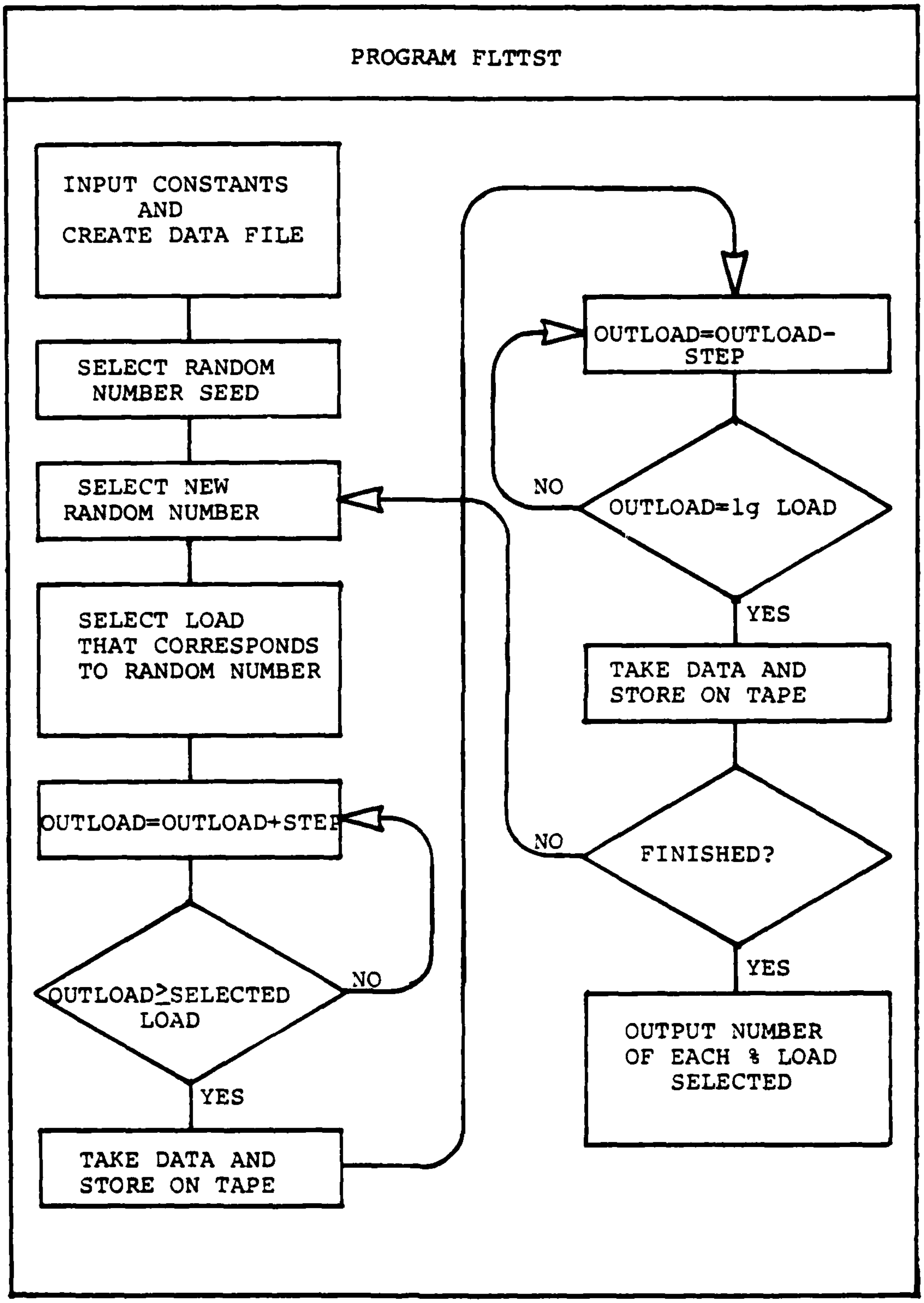
Although several tests and examples of program verification were included in this thesis, many more checks were performed to insure that the system was operating correctly. The only area in which problems occurred was with the Program AXIAL. If enough data points are not taken, E will still be evaluated correctly but the Ramberg-Osgood coefficients will suffer greatly in accuracy.

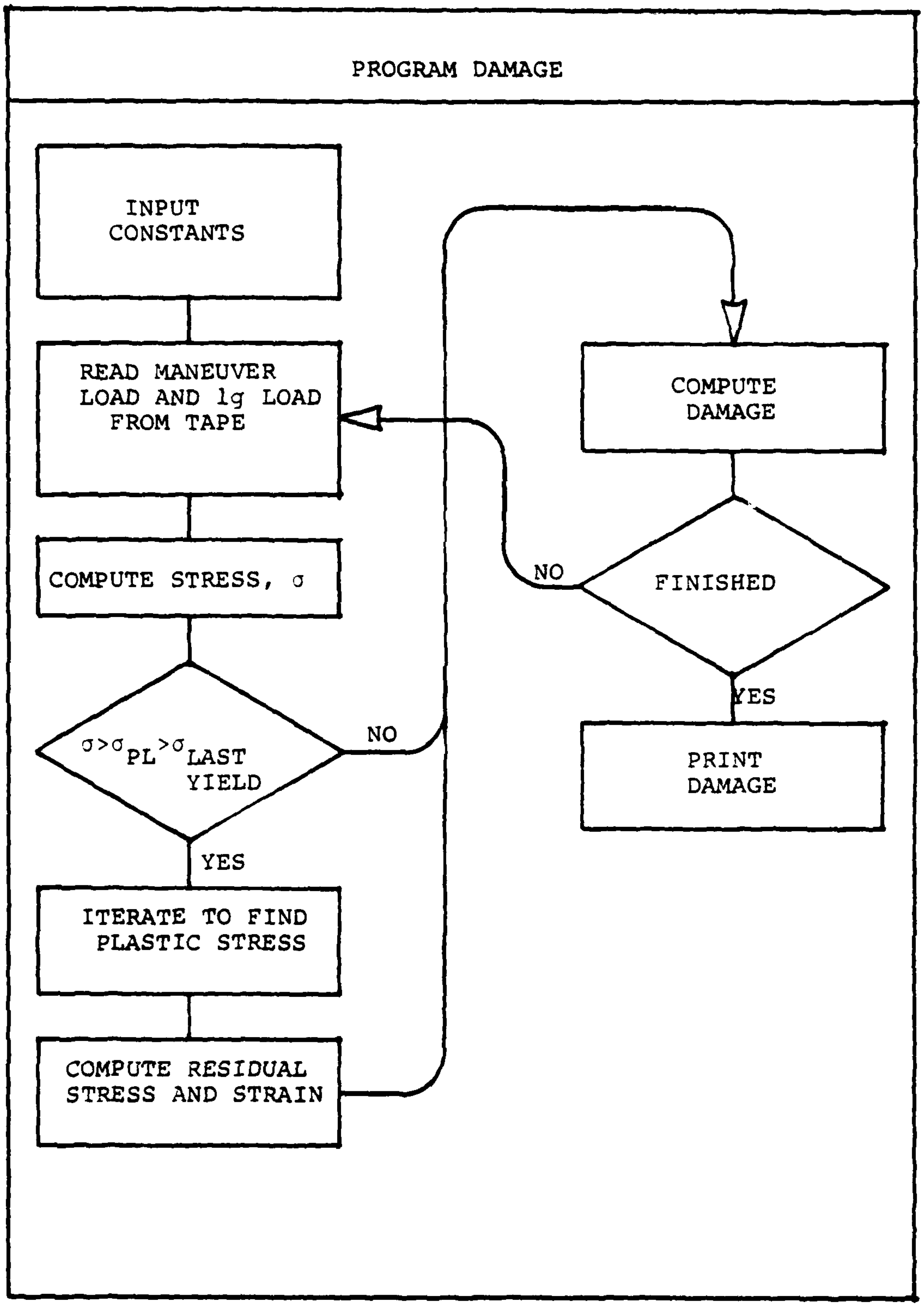
Even though these programs will greatly enhance analysis in the fatigue testing area, the potential of the data acquisition system has barely been tapped. The system as it now stands could handle over twice as much data input and output. With added control cards, the system could be expanded at least tenfold.

APPENDIX A

PROGRAM FLOW CHARTS




PROGRAM FLTTST
INPUT CONSTANTS AND CREATE DATA FILE
SELECT RANDOM NUMBER SEED
SELECT NEW RANDOM NUMBER
SELECT LOAD THAT CORRESPONDS TO RANDOM NUMBER
OUTLOAD=OUTLOAD+STEP
OUTLOAD≥SELECTED LOAD
NO
YES
TAKE DATA AND STORE ON TAPE
OUTLOAD=OUTLOAD-STEP
OUTLOAD=1g LOAD
NO
YES
TAKE DATA AND STORE ON TAPE
FINISHED?
NO
YES
OUTPUT NUMBER OF EACH % LOAD SELECTED


PROGRAM DAMAGE
INPUT CONSTANTS
READ MANEUVER LOAD AND 1g LOAD FROM TAPE
COMPUTE STRESS, σ
σ>σPL>σLAST YIELD
NO
YES
ITERATE TO FIND PLASTIC STRESS
COMPUTE RESIDUAL STRESS AND STRAIN
COMPUTE DAMAGE
FINISHED
NO
YES
PRINT DAMAGE

APPENDIX B

PROGRAM LISTINGS

```
10   REM PROGRAM AUTO START
20   REM
30   LOAD KEY "KEYDAT"
40   PRINT "THE SYSTEM IS NOW SET TO USE FOR DATA ACQUISITION"
50   PRINT "FOR EITHER AN AXIAL MATERIALS TEST OF FATIGUE TESTING."
60   PRINT "TURN ON THE HP-2240A PROCESSOR AND ALLOW TO WARM UP FOR"
70   PRINT "AT LEAST FIVE (5) MINUTES.  THE FOLLOWING IS A LIST OF"
80   PRINT "PROGRAMS AVAILABLE AND THEIR GENERAL PURPOSE.  BY EXECUTING"
90   PRINT "THE SPECIAL KEY THE PROGRAM SELECTED WILL BE LOADED."
100  PRINT "PRESS RUN FOR EXECUTION.  EACH PROGRAM HAS A DETAILED"
110  PRINT "DESCRIPTION OF ITS USE AT THE START."
120  PRINT "   "
130  PRINT "KO      AXIAL MATERIAL PROPERTIES TEST."
140  PRINT "           COMPUTES MODULUS OF ELASTICITY AND POISSON'S RATIO."
150  PRINT "K1      FLIGHT LOADING TEST."
160  PRINT "           APPLIES RANDOM LOADS AND TAKES UP TO EIGHT STRAIN"
170  PRINT "           READINGS AND STORES ON TAPE FILE."
180  PRINT "K2      READ DATA."
190  PRINT "           SEPARATES STRAINS ON TAPE GENERATED BY FLIGHT"
200  PRINT "           TEST ONTO A SEPARATE TAPE FOR EACH STRAIN"
210  PRINT "           AND LISTS A PRINTOUT OF THAT DATA SET."
220  PRINT "           MUST BE RUN BEFORE 'DAMAGE' IF MORE THAN ONE"
230  PRINT "           DATA SET WAS TAKEN!"
240  PRINT "K3      DAMAGE CALCULATION."
250  PRINT "           CALCULATES THE FATIGUE DAMAGE DONE DURING FLIGHT"
260  PRINT "           TEST"
270  END
```

```
KEY 0
  -KEY 7
  "AXIAL"
  -EXECUTE

KEY 1
  -KEY 7
  "FLTTST"
  -EXECUTE

KEY 2
  -KEY 7
  "RDDATA"
  -EXECUTE

KEY 3
  -KEY 7
  "DAMAGE"
  -EXECUTE
```

```
10   PRINT "THIS PROGRAM IS FOR AXIALLY TESTING A MATERIAL SPECIMEN"
20   PRINT " TO FIND THE MODULUS OF ELASTICITY, POISSON"S RATIO AND"
30   PRINT "THE RAMSBURG-OSGOOD COEFFICIENTS FOR THE PLASTIC REGION."
40   PRINT "TWO STRAINS (LONGITUDINAL AND TRANSVERSE) HAVE TO BE INPUT"
50   PRINT "FOR POISSON"S RATIO TO BE COMPUTED.  THE LOAD SHOULD"
51   PRINT "INPUT ON CHANNEL ONE (1).  THE LONGITUDINAL"
60   PRINT "STRAIN SHOULD BE ON CHANNEL TWO (2).  AFTER THE RUN HAS"
70   PRINT "BEEN MADE THE PROGRAM WILL ASK FOR THE MAXIMUM ELASTIC
80   PRINT "LOAD IN ORDER TO COMPUTE E.  AFTER COMPUTING E IT WILL"
90   PRINT "PRINT IT ALONG WITH THE CORRELATION FACTOR AND ASK IF"
100  PRINT "YOU WISH TO TRY ANOTHER FIT.  THEN THE RAMSBURG-OSGOOD"
110  PRINT "COEFFICIENTS WILL BE COMPUTED."
120  REM
130  REM  MAIN PROGRAM FOR MATERIALS TESTING
140  REM
150  DIM LOAD (1000), E1(1000), E2(1000), SIGMA(1000)
160  INPUT "MAX STRAIN/DISPLACEMENT/LOAD? (IN/IN, IN/LBS)," EMX
170  INPUT "STRAIN/DISPLACEMENT/LOAD RATE? (IN, LBS/MIN)," RATE
180  INPUT "NUMBER OF DATA POINTS:," DPTS
190  INPUT "NUMBER OF STRAINS (1/2)," NSTRN
200  INPUT "CROSS-SECTION AREA:," AREA
201  INPUT "LOAD SCALE FACTOR:," LF
202  INPUT "STRAIN SCALE FACTOR:," SF
210  WAIT-TIME=EMX*60000/(RATE*DPTS)
220  DISP "WHEN READY TO START TAKING DATA HIT CONTINUE"
230  PAUSE
231  DISP "RUNNING"
240  FOR I=1 TO DPTS
250     OUTPUT 701; "AI, 2, 1, 3!"
260     ENTER 701;CODE, LOAD(I), E1(I), E2(I)
270     IF CODE()0 THEN 250
271     WAIT WAIT-TIME
280  NEXT I
290  CALL DATA-CONV(LOAD(*), E1(*), E2(&), SIGMA(&), AREA, DPTS, LF, SF)
300  INPUT "INPUT MAX LOAD OF ELASTIC RANGE:," ELMAX
310  FOR N=1 TO DPTS
320     IF LOAD(N))ELMAX THEN 340
330  NEXT N
```

```
330 NEXT N
340 NN=N-1
350 CALL LINFIT(E1(*), SIGMA(*), E, B, RCORR, NN)
360 PRINT "E=";E,"B=";B,"CORRELATION FACTOR=";RCORR
370 IF NSTRN=1 THEN 420
380 CALL LINFIT(E2(*), SIGMA(*), C, D, RCORR, NN)
390 PRINT "C=";C,"D=";D,"CORRELATION FACTOR=";RCORR
400 PRATIO=-E/C
410 PRINT "POISSON'S RATIO=";PRATIO
420 INPUT "WISH TO TRY ANOTHER FIT? (Y/N," ANS$
440 IF ANS$="Y" THEN 300
450 CALL RAMS-OSC(SIGMA(*), E1(*), E, BETA, NEX, DPTS)
460 PRINT "BETA="; BETA, "N="; NEX
470 STOP
480 END
490 SUB LINFIT (XOBS(*), YOBS(*), StOPE, B, RCORR, M)
500 SMXPSQ=SMYPSQ=SMXPYP=SUMX=SUMY=0
510 RECIPM=1/(1*M)
520 FOR I=1 TO M
530    SUMX=SUMX+XOBS(I)
540    SUMY=SUMY+YOBS(I)
550 NEXT I
560 XBAR=SUMX*RECIPM
570 YBAR=SUMY*RECIPM
580 REM NORMALIZE DATA POINTS, COMPUTE MEANS
590 XBARRC=1/XBAR
600 YBARRC=1/YBAR
610 FOR I=1 to M
620    XPRIME=XBARRC*(XOBS(I)-XBAR)
630    YPRIME=YBARRC*(YOBS(I)-YBAR)
640    SMXPSQ=SMXPSQ+XPRIME*XPRIME
650    SMYPSQ=SMYPSQ+YPRIME"YPRIME
660    SMXPYP=SMXPYP+XPRIME*YPRIME
670 NEXT I
680 REM SOLVE FOR NORMALIZED SLOPE
690 DISC=SQR((SMYPSQ-SMXPSQ)↑2+4&SMXPYP↑2)
700 MPRIME=(SMYPSQ-SMXPSQ+DISC)/(2*SMXPYP)
710 REM COMPUTE SLOPE OF UNNORMALIZED BEST LINE
720 SLOPE=MPRIME*YBAR*XBARRC
```

```
740  B=YBAR-SLOPE*XBAR
750  REM COMPUTE REGRESSION POINTS FOR DEVIAT
760  SLRECN=-1/SLOPE
770  DETER=1/(SLOPE-SLRECN)
780  DEVIAT=0
790  FOR I=1 TO M
800     XREG=(YOBS(I)-SLRECN*XOBS(I)-B)*DETER
810     YREG=(SLOPE*YOBS(I)+XOBS(I)-SLRECN*B)*DETER
820     DELX=XREG-XOBS(I)
830     DELY=YREG-YOBS(I)
840     DEVIAT=DEVIAT+SQR(DELX↑2+DELY↑2)
850     SUMXR=SUMXR+(XOBS(I)-XBAR)↑2
860     SUMYR=SUMYR+(YOBS(I)-YBAR)↑2
870  NEXT I
880  RCORR=SLOPE*SQR(SUMXR/SUMYR)
890  SUBEND
900  SUB DATA-CONV(LOAD(*), E1(*), E2(*), SIGMA(*), AREA, DPTS, LF, SF)
910  FOR I=1 TO DPTS
920     SIGMA(I)=LOAD(I)*LF/AREA
930     E1(I)=E1(I)*1.0E-6*SF
940     E2(I)=E2(I)*1.0E-6*SF
950  NEXT I
960  SUBEND
970  SUB RAMS-OSG(SIGMA(*), E1(*), E, BETA, NEX, DPTS)
980  FOR I=1 TO DPTS
990     EP85=SIGMA(I)/(.85*E)
1000    M=I
1010    IF EP85(E1(I) THEN 1030
1020 NEXT I
1030 FOR II=1 TO DPTS
1040    EP70=SIGMA(II)/(.7*E)
1050    N=II
1060    IF EP70(E1(II) THEN 1080
1070 NEXT II
1080 IF ABS(E1(M)-EP85)(ABS(E1(M-1)-EP85) THEN 1110
```

```
1090 SIG85=SIGMA(M-1)
1100 GOTO 1120
1110 SIG85=SIGMA(11)
1120 IF ABS(E1(N)-EP70)(ABS(E1(N-1)-EP70) THEN 1150
1130 SIG70=SIGMA(N-1)
1140 GOTO 1160
1150 SIG70=SIGMA(N)
1160 NEX=1+LOG(17/7)/LOG(SIG70/SIG85)
1170 BETA=3/7*(E/SIG70)↑(NEX-1)
1180 SUBEND
```

```
10   PRINT "   THIS PROGRAM USES THE HP-2240A TO INTERFACE WITH THE"
20   PRINT "MTS SYSTEM TO OUTPUT LOAD AND TAKE DATA, TURN THE 2240A"
30   PRINT "ON AND ALLOW A FIVE MINUTE WARM-UP BEFORE USING."
40   PRINT "   THE PROGRAM PRODUCES RANDOM LOADS TO MEET THE MIL SPECS"
50   PRINT "FOR FATIGUE PER 1000 FLIGHT HOURS.  THE LOADS THAT MUST BE"
60   PRINT "ENTERED ARE THE CALCULATED 1 G AND LIMIT LOADS FOR THE SPEC-"
70   PRINT "IMEN BEING TESTED.  THE MAXIMUM LOAD WILL BE 125% OF THE"
80   PRINT "LIMIT LOAD SO BE SURE THAT THE MTS IS SET ON THE PROPER SCALE."
90   PRINT "THE NUMBER OF FLIGHT HOURS THAT THE SPECIMEN IS TO BE TESTED"
100  PRINT "CAN BE SPECIFIED BY THE USER AND THE PROGRAM WILL USE PROBAB-"
110  PRINT "ILITY TO DETERMINE THE ACTUAL NUMBER OF LOADS.  A PRINT-OUT"
120  PRINT "OF THE NUMBER OF LOADS IN EACH PERCENT OF LIMIT LOAD WILL"
130  PRINT "BE AT THE END OF THE PROGRAM."
140  PRINT "   DATA TAKEN WILL BE STORED ON TAPE UNDER THE NAME SPECIFIED"
150  PRINT "BY THE USER, ALL DATA WILL BE STORED USING SHORT PRECISION"
160  PRINT "AND THE FIRST THREE ENTRIES WILL BE: NUMBER OF STRAINS,"
170  PRINT "NUMBER OF FLIGHT HOURS TESTED, AND NUMBER OF DATA POINTS."
180  PRINT "THE MAXIMUM NUMBER OF STRAINS IS EIGHT."
190  REM
200  REM
210  REM PARAMETER INPUT SECTION
220  REM
230  REM
240  OVERLAP
250  OPTION BASE 1
260  INTEGER NUMSTRAIN
270  SHORT ST(8)
280  SHORT NUMHRS, NUMPTS
290  INPUT "NAME OF DATA FILE?", A$
300  INPUT "NUMBER OF FLIGHT HOURS?", NUMHRS
310  INPUT "NUMBER OF DATA READINGS? (MAXIMUM 8)," NUMSTRAIN
320  NUMPTS=42006*NUMHRS/1000
330  NUMREC=(8*NUMSTRAIN*NUMPTS+12)/256+1
340  CREATE A$, NUMREC
350  ASSIGN #1 TO A$
360  BUFFER #1
370  PRINT #1; NUMSTRAIN, NUMHRS, NUMPTS
380  INPUT "ONE G LOAD? (LBS)," ONEGLOAD
```

```
390  INPUT "LIMIT LOAD? (LBS)," LIMLOAD
400  INPUT "MTS SCALE? (10000, 20000, 50000, 100000,)," SCALE
410  ONEGLOAD=ONEGLOAD*10000/SCALE
420  LIMLOAD=LIMLOAD*10000/SCALE
430  INPUT "LOADING STEP SIZE? (25 TYP.)," STEP
440  INPUT "DATA READING SCALE FACTOR? (MICROSTRAIN/MILLIVOLT OR LBS/MILLIVOLT)
,STRAINSCALE
450  INPUT "PERCENT OF LIMIT LOAD ABOVE WHICH PHOTOS WILL BE TAKEN," PF
460  PHOTO-FLAT=PF/100
470  DISP "WHEN READY TO RUN HIT CONTINUE"
480  PAUSE
490  REM
500  REM
510  REM OUTPUT RANDOMIZED LOADS AND TAKE DATA
520  REM
530  REM
540  OUTPUT 701; "AO, 1, 2, 1, 0!"
550  OUTPUT 701; "AC, 2!"
560  DISP "RUNNING"
570  RANDOMIZE
580  PRINT "LOAD AT WHICH PHOTO WAS TAKEN (LBS)"
590  FOR J=1 TO NUMPTS
600  SEED=RND
610  IF SEED(17000/42006 THEN 710
620  IF SEED(26500/42006 THEN 740
630  IF SEED(33000/42006 THEN 770
640  IF SEED(27500/42006 THEN 800
650  IF SEED(40000/42006 THEN 830
660  IF SEED(41360/42006 THEN 860
670  IF SEED(41800/42006 THEN 890
680  IF SEED(41950/42006 THEN 920
690  IF SEED(41990/42006 THEN 950
700  GOTO 980
710  XLOAD=.35*MLOAD
720  NUM35-NUM35+1
730  GOTO 1000
740  XLOAD=.45*LIMLOAD
750  NUM45-NUM45+1
```

```
760   GOTO 1000
770   XLOAD=.55*LIMLOAD
780   NUM55=NUM55+1
790   GOTO 1000
800   XLOAD=.65*LIMLOAD
810   NUM65=NUM65+1
820   GOTO 1000
830   XLOAD=.75*LIMLOAD
840   NUM75=NUM75+1
850   GOTO 1000
860   XLOAD=.85*LIMLOAD
870   NUM85=NUM85+1
880   GOTO 1000
890   XLOAD=.95*LIMLOAD
900   NUM95=NUM95+1
910   GOTO 1000
920   XLOAD=1.05*LIMLOAD
930   NUM105=NUM105+1
940   GOTO 1000
950   XLOAD=1.15*LIMLOAD
960   NUM115=NUM115+1
970   GOTO 1000
980   XLOAD=1.25*LIMLOAD
990   NUM125=NUM125+1
1000 OUTLOAD=OUTLOAD+STEP                              !INCREASE TO
1010 OUTPUT 701; "A0, 1, 1, 1,",OUTLOAD,"!"           ! RANDOM
1020 IF OUTLOAD(XLOAD THEN 1000                        !  LOAD
1030 IF XLOAD(PHOTO-FLAG*LIMLOAD THEN 1080
1040 PRINT XLOAD*STRAINSCALE
1050 OUTPUT 701; "AO, 1, 2, 1, 10000!"
1060 WAIT 200
1070 OUTPUT 701; "AO, 1, 2, 1, 0!"
1080 FOR I=1 TO NUMSTRAIN
1090 OUTPUT 701; "AI, 2, ", I, "1!"
1100 ENTER 701; C, ST(I)
1110 IF C=1 THEN 1090                                  !CHECK FOR GOOD DATA
1120 ST(I)=ST(I)*STRAINSCALE                           !STORE DATA
1130 PRINT #1;ST(I)                                    !    ON
```

```
1140 NEXT I                                              !  TAPE
1150 OUTLOAD=OUTLOAD-STEP                                !RETURN TO
1160 OUTPUT 701; "A0, 1, 1, 1,",OUTLOAD,"!"              ! ONE-G
1170 IF OUTLOAD)ONEGLOAD THEN 1150                       !  LOAD
1180 FOR I=1 TO NUMSTRAIN
1190 OUTPUT 701;"AI, 2,",I,"1!"                          !GET ONE-G DATA
1200 ENTER 701;C,ST(I)
1210 IF C=1 THEN 1190                                    !CHECK FOR GOOD DATA
1220 ST(I)=ST(I)*STRAINSCALE                             !STORE DATA
1230 PRINT #1;ST(I)                                      !  ON
1240 NEXT I                                              !  TAPE
1250 NEXT J
1260 OUTPUT 701;"A0,1,1,1,0!"
1270 OUTPUT 701;"A0,1,2,1,10000!"
1280 WAIT 200
1290 OUTPUT 701;"a0,1,2,1,0!"
1300 PRINT "PERCENT LIMIT LOAD," "NUMBER OF LOADS"
1310 PRINT "35," NUM35
1320 PRINT "45," NUM45
1330 PRINT "55," NUM55
1340 PRINT "65," NUM65
1350 PRINT "75," NUM75
1360 PRINT "85," NUM85
1370 PRINT "95," NUM95
1380 PRINT "105," NUM105
1390 PRINT "115," NUM115
1400 PRINT "125," NUM125
1410 DISP "END"
1420 END
```

```
10   PRINT "THIS PROGRAM TAKES DATA THAT HAS BEEN STORED"
20   PRINT "WITH THE 'FLTTST' PROGRAM AND SEPARATES THE"
30   PRINT "DIFFERENT STRAINS OR LOADS RECORDED AND STORES"
40   PRINT "EACH ON ITS OWN SEPARATE FILE.  HOWEVER, IT ONLY"
50   PRINT "DOES THIS FOR ONE STRAIN AT A TIME.  THE PROGRAM"
60   PRINT "WILL HAVE TO BE RE-ENTERED FOR EACH STRAIN THAT"
70   PRINT " IS TO BE SEPARATED.  THE REQUIREMENTS FOR THIS"
80   PRINT "PROGRAM ARE THE NAMES OF THE ORIGINAL DATA FILE"
90   PRINT "AND THE NAME OF THE NEW FILE TO BE CREATED."
100  OPTION BASE 1
110  SHORT ST(8)
120  SHORT NUMHRS, NUMPTS
130  INTEGER NUMSTRAIN
140  SHORT STS
150  INPUT "NAME OF DATA FILE?", A$
160  ASSIGN #1 to A$
170  BUFFER #1
180  READ #1; NUMSTRAIN, NUMHRS, NUMPTS
190  PRINT "STRAINS," "FLIGHT HOURS," "DATA POINTS"
200  PRINT NUMSTRAIN, NUMHRS, NUMPTS
210  INPUT "STRAIN TO BE READ? (1-8)," STNUM
220  INPUT "NAME OF NEW FILE?", B$
230  NUMREC=(8*NUMPTS+3)/256+1
240  CREATE B$, NUMREC
250  ASSIGN #2 to B$
260  BUFFER #2
270  PRINT #2; NUMSTRAIN, NUMHRS, NUMPTS
280  FOR I-1 to NUMPTS*2
290  FOR J=1 TO NUMSTRAIN
300  READ #1; ST(J)
310  NEXT J
320  STS=ST(STNUM)
330  PRINT #2; STS
340  NEXT I
350  READ #2, 1
360  READ #2; NUMSTRAIN, NUMHRS, NUMPTS
370  PRINT "FLIGHT HOURS," "DATA POINTS"
```

```
380  PRINT NUMHRS, NUMPTS
390  PRINT "LOADED," "1 G"
400  FOR I=1 TO NUMPTS*2 STEP 2
410  READ #2; STSLOAD, STS1G
420  PRINT STSLOAD, STS1G
430  NEXT I
440  END
```

```
10   PRINT "THIS PROGRAM IS USED TO CALCULATE FATIGUE DAMAGE"
20   PRINT "FROM DATA OBTAINED BY USING THE FLIGHT TEST PROGRAM."
30   PRINT "THE FOLLOWING INPUTS ARE NEEDED FOR THE PROGRAM:"
40   PRINT "   AREA                      CROSS SECTIONAL AREA OF SPECIMEN"
50   PRINT "   E                         MODULUS OF ELASTICITY"
60   PRINT "   BETA, N                   RAMSBERG-OSGOOD COEFFICIENTS"
70   PRINT "   KT                        STRESS CONCENTRATION FACTOR"
80   PRINT "   LIMIT                     PROPORTIONAL LIMIT"
90   PRINT "THE PROGRAM USES MINER'S METHOD TO CALCULATE THE DAMAGE."
100  PRINT "AFTER THE PROPORTIONAL LIMIT HAS BEEN PASSED THE RESIDUAL"
110  PRINT "STRESS AND STRAIN ARE CALCULATED AND ALL STRESSES ARE THEN"
120  PRINT "CALCULATED WITH CORRECTIONS FOR RESIDUAL STRESS AND STRAIN."
130  REM
140  REM
150  REM MAIN PROGRAM FOR DAMAGE CALCULATION
160  REM
170  REM
180  SHORT NUMHRS, NUMPTS, LOAD, ONEGLOAD, NUMST
190  COM E, BETA, CN, KT, SIGY, SL, SYMAX, D
191  D=0
200  INPUT "AREA?",AREA
210  INPUT "MODULUS OF ELASTICITY?",E
220  INPUT "RAMSBURG-OSGOOD COEFFICIENT, BETA?",BETA
230  INPUT "EXPONENT, N?", CN
240  INPUT "STRESS CONCENTRATION FACTOR, KT?", KT
250  INPUT "PROPORTIONAL LIMIT?", SIGY
260  INPUT "NAME OF DATA FILE?", A$
270  ASSIGN #1 to A$
280  BUFFER #1
290  READ #1; NUMST, NUMHRS, NUMPTS
300  PRINT "FLIGHT HOURS = ",NUMHRS
310  PRINT "NUMBER OF DATA POINTS = ",NUMPTS
320  I=1
330  IF I)=NUMPTS THEN 600
340  READ #1; LOAD, ONEGLOAD
350  I-I+1
360  SL-LOAD/AREA
370  SIG=ONEGLOAD/AREA
```

```
380  SIGL=SL*KT
390  SIG1G=S1G*KT
400  IF SIGL)SIGY THEN 430
410  CALL DAMCALC(SIGL, SIG1G, D)
420  GOTO 330
430  CALL FINDSIG(SIGL)
440  PRINT "INTO PLASTIC RANGE, SIGMA=";SIGL
441  SIGMAX=SIGL
450  SYMAX=SL
460  SIGR=SIGL-SQR(SIGL↑2+2*CN*BETA*E↑2*(SIGL/E)↑(CN+1)/(CN+1)
470  EPR=SIGR/E+BETA*(SIGL/E)↑CN
480  SIG1G=SIGR+KT*S1G-E*EPR*(1+S1G/SYMAX)
481  PRINT " RESIDUAL STRESS=";SIGR
482  PRINT " RESIDUAL STRAIN=";EPR
483  PRINT " NEW 1-G STRESS=";SIG1G
490  CALL DAMCALC(SIGL,SIG1G,D)
500  IF I)=NUMPTS THEN 600
510  READ #1; LOAD, ONEGLOAD
520  I=I+1
530  SL=LOAD/AREA
540  S1G=ONEGLOAD/AREA
560  SIGL=SIGR+KT*SL-E*EPR*(1+SL/SYMAX)
561  IF SIGL)S1GMHX THEN 430
570  SIG1G=SIGR+KT*S1G-E*EPR*(1+S1G/SYMAX)
580  CALL DAMCALC(SIGL, SIG1G,D)
590  GOTO 500
600  PRINT "FLIGHT HOURS," "DAMAGE"
610  PRINT NUMHRS, D
620  END
630  SUB FINDSIG(SIGL)
640  COM E, BETA, CN, KT, SIGY, SL, SYMAX
650  SIG1=SIGY*.7
660  SIG2=SL*KT
670  CN1=CN-1
680  F1=KT-(1+BETA*(SIG1/E)↑CN1)*SIG1/SL
690  F2=KT-(1+BETA*(SIG2/E)↑CN1)*SIG2/SL
700  X=(SIG1*F2-SIG2*F1)/(F2-F1)
710  FX=KT-(1+BETA*(X/E)↑CN1)*X/SL
```

```
710  FX=KT-(1+BETA*(X/E)↑CN1)*X/SL
720  IF ABS(F1)).0000001 THEN 750
730  SIGL=SIG1
740  SUBEXIT
750  IF ABS(F2)).0000001 THEN 780
760  SIGL=SIG2
770  SUBEXIT
780  IF F1*F2)0 THEN 830
790  SIG2=X
800  F2=FX
810  F1-F1/2
820  GOTO 680
830  SIG1=X
840  F1=FX
850  F2=F2/2
860  GOTO 680
870  SUBEND
880  SUB DAMCALC(SIGL, SIG1G, D)
890  R=SIG1G/SIGL
900  S=SIGL/10000
910  N1-12.6452-1.92662*S+.00281098*S↑4-3.10691E-7*S↑8
920  N2=-12.8099*R 2+212.476+R↑6-86.765*R↑8+3.688*S*R
930  N3=-.11272*S↑3*R+.00104762*S↑5*R+3.39637E-6*S↑7*R↑3
950  N4=-.0350885*S↑3*R↑4-.0161827*S↑4*R↑6-34.4642*S*R↑9
951  NN=N1+N2+N3+N4
952  IF NN)6 THEN 990
960  N=10↑NN
980  D=D+1/N
990  SUBEND
```

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